FINAL PROGRESS REPORT
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Overview:

This grant covered two separate but related activities funded in response to an initial proposal entitled "Establishment of a GPS Geodetic Network in the Southern Aegean Sea" and a subsequent proposal entitled " Analysis and Interpretation of Southern Aegean GPS Data: A Comparison of Alternative Data Reduction Algorithms." At the request of NASA, these two awards were merged into one grant. This report summarizes our accomplishments to date on both activities.

Establishment of a GPS Geodetic Network in the Southern Aegean Sea:

Under the initial award, together with funding from NSF and with invaluable help from Greek colleagues, a network of GPS sites covering the southern half of the Aegean was selected, monumented and documented. Procedures are outlined in Avdis et al (1990), a copy of which is enclosed. In October 1988, GPS observations were made at these newly established sites, together with the satellite laser ranging (SLR) sites at Dionysus, Xrisokellaria, Roumeli, Katavia and Askites. The GPS campaign was a collaborative effort involving scientists and equipment from the National Technical University (Athens), Lamont-Doherty Geological Observatory, the Institute of Applied Geodesy (IfAG: Frankfurt, West Germany), and the University of Colorado (UNAVCO). Experimental design, data collection methods, data quality, observation schedules, equipment and logistics of this observation campaign are detailed in a report entitled "Report of GPS measurements in the southern Aegean region, Greece, October 9-23, 1988," previously submitted to NASA.

Analysis and Interpretation of Southern Aegean GPS Data:

Bernese Software: Processing of the 1988 southern Aegean GPS data was started at Lamont in early winter of 1988 using the second generation Bernese software. In the spring of 1989, the third generation Bernese software was brought to Lamont and processing continued on this improved system. At this time the Bernese software removed cycle slips in differenced data, and the process of identifying and manually removing the cycle slips from the Aegean data proved quite difficult. In summer and early fall 1989, Dr. Chris Rocken at the University of Colorado ported the Turboedit cycle-slip editing software into the Bernese software. During the visit of Demitris Paradissis to Lamont in November 1989, the Turboedit cycle slip editing procedure was successfully applied to the Aegean data, and a preliminary solution was obtained through the Bernese software. By late 1989, however, we were convinced that the GIPSY software offered a more versatile and illuminating approach to the data set; at about that same time, we learned that our German colleagues at the University of Bonn and the Institute of Applied Geodesy were beginning an analysis of our jointly-collected data using the Bernese software. In the interests of both efficiency and international goodwill we have now stopped pursuing the Bernese analysis, leaving this effort in the hands of our German colleagues.

GIPSY Software: In June/July and again in September, 1989, Ken Hurst travelled to the Jet Propulsion Laboratory (JPL) to learn and to use the GIPSY GPS analysis software. GIPSY includes a robust editor for undifferenced GPS phase data, which substantially reduces the analysis effort on data recorded with instruments that use the P

code (including the eight TI4100 receivers used during the 1988 campaign, but not the Minimac receiver stationed at the Askites SLR site). In addition, GIPSY includes a set of post-processor software which allow solutions to be rigorously combined. As a consequence, the analysis can be split up into smaller, more manageable pieces, and the analyst can more readily isolate a particular problem in a data set. During his 1989 visits to JPL and since his employment as a JPL scientist in 1990, Hurst has succeeded in analyzing all of the TI4100 data through bias free, single-day-arc solutions, and seven days of the TI4100 data through bias fixed, single-day-arc solutions. Bias fixing proceeed smoothly for all biases on baselines within Greece from these seven days once a good bias-free solution had been obtained. The TI4100 data set includes seventeen of the eighteen sites occupied in Greece, plus the fiducial sites at Wetzell (Germany), Onsala (Sweden), Westford (Massachusetts), Richmond (Florida) and Mojave (California). Examples of results from the TI4100 GIPSY analysis were included in an earlier progress report dated 1 May 1990. Repeatability of baseline lengths measured between the same stations on different days is on the order of five parts in 10^8, or five millimeters over our typical baseline length of about one hundred kilometers for the bias fixed solutions. Comparison between baselines measured with satellite laser ranging and the same baselines measured with GPS shows that the GPS results are within the scatter of the SLR solutions obtained by different SLR research groups.

Minimac/Askites Problem: Unfortunately, efforts to add the last data set, collected with a Minimac receiver at the Askites SLR site, have not been successful to date. During preparation for the 1988 field campaign, we recognized a potential timing problem in that the TI4100 collects data at 29.08 seconds and 59.08 seconds after the even minute as determined in GPS time, whereas the Minimac collects data at a selectable interval of integer seconds, starting on the even minute in UTC time. UTC time differs from GPS time by 5 seconds. In order for double differencing to work, the phase measurements at the stations to be differenced should coincide in time; otherwise, one set must be interpolated with less satisfactory results. We tackled this problem by collecting data on the Minimac at a 6 second data rate. Because of the GPS-UTC offset, the Minimac recorded data at (among other times) 59.00 and 29.00 sec after the even GPS minute, only 0.08 sec different from the TI4100 time. The major drawback of this mode of operation was that the memory of the receiver filled up after about 20min of tracking, and tracking had to stop for 3 to 5 minutes while the data was transferred to floppy disk. Work to date on the Minimac data has verified that the receiver maintained lock during the data transfer, so that extra phase bias parameters are not needed, and there is no obvious inherent reason why the data should not be analyzable; nonetheless, whenever Minimac and TI4100 data are combined into the same solution attempt, the solution fails. We suspect that the editing of the Minimac data (which does not include the P-code information ordinarily needed by Turboedit) is flawed. A number of automatic editing schemes have been explored, but none has proved completely reliable. An identical problem has been encountered by GIPSY-users trying to combine data from Rogue and Minimac receivers. Because most of the CIGNET tracking network has now switched to Minimac receivers, devising techniques to combine different data types is a high priority for the GPS community. We are optimistic that a solution to the Askites problem will be forthcoming, either through our own efforts or through the parallel efforts of other research groups, but we are unable to present a complete analysis of all eighteen Aegean GPS sites at this time.

Future: When the Minimac problem is solved, the last remaining analysis steps will be to fix the biases on the days which have not yet been fixed, and then to combine the single day solutions to obtain multi-day satellite arcs. A manuscript is in preparation (Hurst et al, in prep) which (1) presents the analysis of the GPS data, (2) compares the results received by the Lamont group using the GIPSY analysis software with the results achieved by the IfAG group using the Bernese software, and (3) compares the baseline

lengths between SLR sites as measured by GPS with published baselines obtained by SLR.

Publications resulting from this grant:

Avdis, V., H. Billiris, K. Hurst, K. Kastens, D. Paradissis, and G. Veis, in press, Selection, monumentation, and documentation of GPS sites in the circum-Aegean region, Greece, Newsletter of the IUGG Subcommission on Space Geodetic Measurement Sites.

Hurst, K., D. Paradissis and K.Kastens, 1989, Analysis of 1988 Southern Aegean GPS Data, EOS, 70, 1053.

Hurst, K., K. A. Kastens, and others, in prep., Comparison between Global Positioning System (GPS) and Satellite Laser Ranging (SLR) measurements in the circum-Aegean region, for Geophysical Research Letters.

Kastens, K.A., V. Balis, H Billiris, D. Chayes, C. Elsner, H. Friedhoff, H. Habrich, K. Hurst, T Koczynski, P. Milas, A. Mueller, W Mueller, A. Papafitsorou, D. Paradissis, C. Raymond, J. Riecken, B. Sorge, B. Stephens, J. Stowell, D. Tsolakis, J. Tziotzis, G. Veis and C. Vlachos, 1989, The Aegean GPS Project: 1988 Results and 1989 Plans, EOS, 70, 306.

Paradissis, D., H. Billiris, P. England, H. Kahle, K. Kastens, and G. Veis, in review, Use of the Global Positioning System (GPS) for direct measurements of crustal motions in Greece (in Greek, English abstract), submitted to the Journal of the Hellenic Engineering Society.

Education and Human Resources:

Under the auspices of the Aegean GPS project, four American graduate students and post-docs have received training and experience in the use of GPS field techniques. Of these trainees, Nancy Breen has subsequently written and submitted a proposal to use GPS to monitor crustal motions near the Mendicino triple junction; Robin Bell has directed a gravity survey on Lake Malawi using GPS for ship positioning; Carol Raymond is investigating the possibility of using GPS for crustal motion studies in Antarctica; and David Dinter (MIT) is pursuing a PhD thesis on structural geology and basin development in the north Aegean region. In addition, more than a dozen Greek scientists and students have gained hands-on experience in the use of GPS field equipment. Finally, this grant contributed to the very productive visits of two Greek scientists to Lamont: Demitris Paradissis, of the National Technical University in Athens, spent 6 weeks at Lamont in November/December 1989, working with the Bernese GPS analysis software; and Fotini Maltezou of the Public Petroleum Corporation of Greece worked on various aspects of Mediterranean geology while holding a NATO fellowship at Lamont during the first four months of 1990.